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Risk prioritisation of stormwater pollutant sources

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Abstract
This paper describes the development of a pollutant risk prioritisation methodology for the comparative assessment of stormwater pollutants discharged from differing land use types and activities. Guidelines are presented which evaluate available data with respect to 'likelihood of occurrence' and 'severity of impact'. The use of the developed approach is demonstrated through its application to total suspended solids, biochemical oxygen demand, lead and cadmium. The proposed benchmarking scheme represents a transparent and auditable mechanism to support the synthesis of data from a variety of sources and is sufficiently flexible to incorporate the use of chemical, physical and/or ecological data sets. Practitioners involved in developing and implementing pollutant mitigation programmes are assisted in two key ways. Firstly through enabling the risks to receiving waters from diffuse pollution on a source-by-source and/or pollutant-by-pollutant basis at a catchment scale to be comparatively assessed and prioritised. Secondly, the methodology informs the selection of appropriate diffuse pollution control strategies.

Key words: risk assessment; runoff; diffuse pollution sources; urban and rural motorways

1 Introduction

Set against a scenario of climate change and uncertain economic and socio-political futures, it is inevitable that there will be a variety of both new risks and opportunities which will arise in the implementation and management of urban surface water (USW) drainage infrastructure. The priority objectives must be to avoid or minimise increased flooding and pollution risks whilst increasing performance efficiency and enhancing local environmental quality-of-life. Whilst the identification and evaluation of a range of technical (e.g. stormwater best management practices; BMPs) and planning (e.g. low impact development) approaches to manage USW under differing climate and urban change scenarios has been the subject of considerable research from a water quantity perspective (Djordjević et al., 2011, Gallien et al., 2011, Villareal et al., 2004), risks from USW-derived pollution have received comparatively less attention.

Within the United States, USW runoff discharging from separate sewers and industrial estates is covered under the National Pollutant Discharge Elimination System (NPDES) through inclusion of pollutants from non-point sources within the calculation of water body-specific total maximum daily loads (US EPA, 1998). However, this approach is essentially driven by managing the hydraulic requirements of peak storm volume attenuation, storage and treatment on a site-by-site basis, rather than managing the impact of the more frequent, non-extreme flow events which are responsible for most of the annual urban runoff volume and associated mobilisation and transport of pollutants (Donovan and Pfender, 2000, Pitt and Voorhees, 2002, Woods-Ballard et al., 2007). Within Europe, the European Union Water Framework Directive (EU WFD, 2000) specifically refers to the need to tackle diffuse pollution sources on a catchment scale basis, with the establishment of stringent environmental quality standards (EQS) for a diverse range of priority and priority hazardous substances (PS/PHS) in receiving waters providing a further key driver to address USW management from both quantity and quality perspectives (EU EQS, 2008). The concept of catchment-based management is being reviewed by the US EPA for adoption within their NPDES permitting system (US EPA, 2007).

The incorporation of USW quality within wider urban water management strategies requires a detailed understanding of the sources and patterns of release of stormwater pollutants, their mobilisation and transport by non-extreme rainfall events and the impact of mobilised stormwater pollutants on receiving water ecology, with knowledge of these aspects required on a catchment (or sub-catchment) specific basis. As a contribution to addressing this identified need, this paper presents a structured approach to prioritising risks to surface water quality from USW-derived pollutants. Guidelines are developed to support the benchmarking of existing data using chemical, physical and/or ecological descriptors with respect to 'likelihood of occurrence' and 'magnitude of impact'. Once benchmarked, the two sets of derived data can be combined forming the basis for a comparative evaluation and subsequent prioritisation of the risks to receiving waters from a range of stormwater pollutant sources in an approach that is sensitive to variations in both pollutant and land-use characteristics. The developed approach is proposed as a screening approach which can be utilised to enable the risks to receiving water quality from stormwater runoff to be identified and prioritised on a (sub-) catchment basis over both current and longer-term time frames. This provides important input to the development of sustainable water management strategies and in particular, EU WFD Programmes of Measures (PoMs) for the mitigation and management of diffuse pollution risks. Whilst the matrix-based risk methodology is widely recognised (USDA, 2003), the novelty of the current procedure is in its application to stormwater management and the development of a water quality dimension to the risk assessment procedure.

2 Identification of sources of stormwater pollutants

Stormwater surface runoff includes separately sewered discharges from impervious surfaces and overland flows from open spaces, parks/gardens, road verges and construction sites. Groundwater flooding can also act as a significant contributory source particularly during extreme storm events. Figure 1 illustrates the principal pollutant groups and their sources associated with such surface water discharges with surface "dirt and dust" accumulation, metals, organics and nutrients coming from a mix of vehicular wear and traffic emissions, roofing, highway activities, construction materials, commercial activities, litter and plant/leaf debris, spillages and animal/bird excreta in addition to atmospheric deposition. Illicit building connections, sewer cross-connections and in-sewer pollutant transformation add to the "cocktail" of pollutants discharging to the receiving waterbody.

Figure 1 also shows the pollutant pathways which follow the urban hydrological cycle with pathway receptors such as highway surfaces, road gullies and pipe drains acting as both pollutant sinks and reservoirs. The temporary storage of pollutants between sinks can occur, often with extended time delays between passage from one “source” to a subsequent “sink”. This means that there is considerable opportunity for pollutant transformation during conveyance from the original source to the final discharge point. This clearly makes it more difficult to track and attribute specific sources based on final discharge concentrations and loadings. The characteristics of the observed event mean concentration (EMC) distribution in the discharge may then reflect more the nature of the flow properties of the individual event rather than the source characteristics.

It is nevertheless clear that the road/highway surface system acts as a principal source and conveyor of pollutants to the below-ground pipe system and that mitigating measures need to be applied prior to entry into the roadside gully and pipe system. However to achieve maximum quality benefit, the most effective control measures must be applied at the original source in order to minimise receiving water risks. If this is not possible, then alternative passive treatment should be applied prior to discharge. As indicated in Figure 1 by the dashed lines, surface drainage waters can also find their way below-ground as a result of direct infiltration recharge or through pipe exfiltration. This contribution to the sub-surface receiving waterbody may be small in terms of total water volume, but given the potentially high pollutant concentrations that may occur in surface runoff, it could present problems to long term groundwater quality objectives.

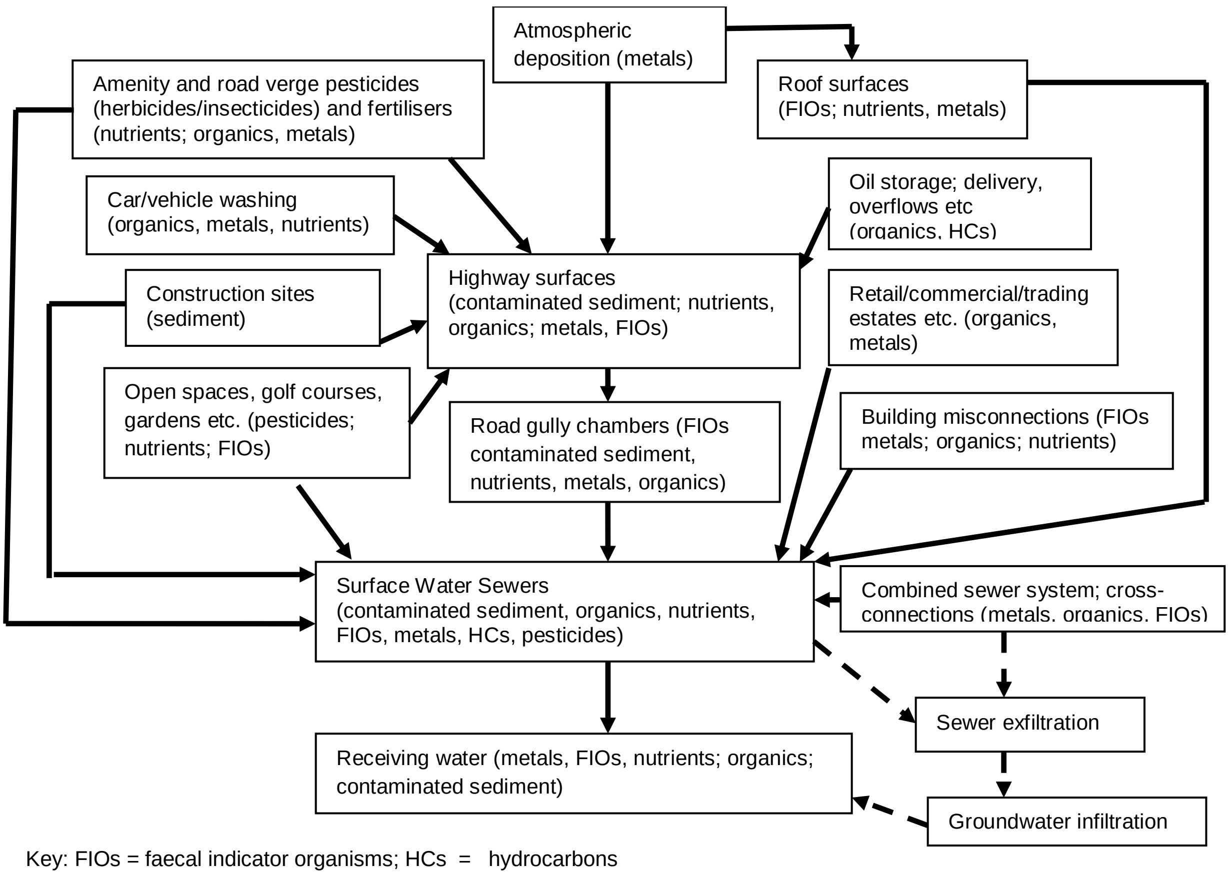

Figure 1. Principal stormwater pollutant sources and types.

3 Pollutant concentrations and loadings

There is now a considerable database available which quantifies EMC distributions and loadings associated with the various priority sources identified in Figure 1, although data in relation to some sources such as car washing and building misconnections are still relatively scarce. Table 1 provides a collation of European data for the main pollutant groups which impose principal pressure in terms of likelihood of prejudicing water quality standards.

The data clearly demonstrates the inherent variability in stormwater runoff EMC distributions and this characteristic property is evident whatever range of storm return period is selected. It is unfortunate that the majority of reported studies fail to note the storm return interval (or even other flow/volumetric information in many cases) associated with the EMC value(s). It has been suggested that there may be a lack of correlation between rainfall return period and EMC distributions given that pollutant concentrations are not only dependent on runoff volume/depth but also intensity, event duration and antecedent condition (Bertrand-Krajewski and Chebbo, 2002). Whilst this may be reasonable, the same study also stressed that very different storm pollutographs lead to similar values of interception efficiency, thus hydraulic volume remains the critical factor. Runoff volumes and intensities increase with less frequent storm return periods such that events >1: 10 RI are likely to substantially buffer other interfering factors. Thus the data in Table 1 includes information which spans storm events from the less than the annual average event (<1:1 return interval, RI) up to at least the 1:30 RI event. However, it is likely that most of the reported data refer to storm events less than the 1:5 RI as can be confirmed by reference to the www.bmpdatabase.org. Although it is not possible to relate identified flows/rainfall depths to specific BMP EMC distributions as the flow and quality data are reported separately, the storm flow volumes tend to be very much less than the design volumes and in many cases would very likely fall below the 1:1 RI event. Thus whilst the database in Table 1 covers the full range of scenarios for the reported EMC and loading values, it can still be reasonably used to judge the exceedance by which the EMC range is above the minimum irreducible concentration (MIC) or ambient background concentration, as well as its relation to the required EU EQS. Both the MIC and EQS values (where available) are given in Table 1.

3.1 Use of event mean concentrations (EMCs), maximum allowable concentrations (MAC) and annual average (AA) concentrations

In contrast to managing the quantity aspects of USW flows (with its focus on the hydrology of extreme events), evaluating the water quality implications of USW flows requires the consideration of smaller, more frequent storm events. In this current study, a non-extreme event is defined as a storm with a return interval of <1 year, with this consideration of smaller-scale storms justifying the use of EMCs to indicate concentrations of selected pollutants typically discharging to surface waters. In relation to surface water EU WFD EQS, standards are typically available as a maximum allowable concentration (MAC-EQS) to protect against short-term, or acute, exposure and/or an annual average concentration (AA-EQS) to provide protection against long-term, or chronic, effects (EU EQS, 2008). As USW discharges are episodic events, the MAC-EQS has been selected as the most appropriate type of standard against which the impact of USW flows on surface water quality may be most usefully assessed. The availability of MIC values provides an additional benchmark against which the magnitude and severity of the EMC impact might be judged. Hence, the

Table 1. Pollutant Magnitude, Source and Impact (based on European data)

Pollutant pressure	Pollutant source	Event mean concentrations	Loadings (kg/ha/yr)	% WFD failures attributable t pollutant source
Nutrients (mg/l)	Misconnections	Total P:39; NH_4:5		<2% (3-5% Dwellings)
	Urban amenity fertiliser	Total P: 0.02-14.3; Total N: 0.4-20; NO_3: 0.1-4.7		2%-8%(Housing; Roads; Golf courses)
Minimum irreducible concentration (MIC):	Residential	Total N:0-6; NH_4:0.4-3.8		2%-3%
Total phosphates: 0.15	Highways, motorways and major roads	Total N:0-4	NH_4: 7.2-25.1	
Total nitrogen:1.9	Commercial	NH_4:0.2-4.6		
	Industrial	NH_4: 0.2-1.1		
	Roofs	NH_4: 0.4-3.8		
	Gully Liquors	Total N:0.7-1.39		
FIOs: *E. coli* (MPN/100ml) MIC: 10^1	Misconnection	10^3-10^6		
	Roofs, roads and parks (e.g. pets, birds)	40-10^6	1-4 x10^8	N/A
Metals (µg/l) Pb Cd Zn Ni Cu	Motorways and major roads	Pb: 3-2410; Zn: 53-3550; Ni:4-70; Cd: 0.3-13	Pb:1.1-13	~5%(Highways
	Urban distributor roads	Pb:10-150; Zn: 410; Cd:0.2-0.5	Pb:0.17-1.9 Zn:1.15	<14%
	Suburban roads	Pb:10-440; Zn: 300	Pb:0.01-1.91 Zn:1.15	
NOTE: metalled roofs not included	Commercial estates	Ni: 2-493		~5% trading estates/car washing
	Residential	Cd: 0-5; Zn: 150; Pb: 0-140	Pb: 0.001-0.03	
	Roofs	Pb:1-30		
	Gully Liquors	Pb:100-0.850		
Total suspended solids (mg/l)	Residential			
	High density	55-1568	130-840	5%-6%
MIC:10-20mg/l	Low density	10-290	50-183	
	Motorways & major Roads	110-5700	815-6289	
	Urban roads	11-5400		
	Roadside gully chambers	15-840	409-1700	
	Industrial	50-2582	620-2340	
	Commercial	12-270		
	Roofs	12.3-216		
	Misconnections	300-511		
Hydrocarbons (µg/l)	Residential			
HC = hydrocarbons	High density	Total HC:0.67-25.0	PAH: 0.002	
PAH = polyaromatic hydrocarbons	Low density	Total HC: 0.89-4.5	TotalHC:1.8	
	Motorways & Major Roads	Total HC:7.5-400; PAH:0.03-6	Total HC: 0.01-43.3; PAH:140	
	Urban roads	Total HC: 2.8-31; PAH: 1-3.5		
	Commercial	Total HC:3.3-22; PAH:0.35-0.6	PAH:0.01-0.35	
	Industrial	Total HC:1.7-20	PAH:0.07	
Pesticides (µg/l) (Glyphosate)	Rural motorways	0.025-0.4		
	Urban motorways	0-17.5		
	Urban roads	0.4-48.1		
Organics (mg/l) (Biochemical oxygen demand)	Residential			
	High density	2-17	2.8-76	
	Low density	0-4		
MIC: 2-4	Commercial	5-22	43-172	
	Industrial	8-23		
	Roofs	2.8-8.1		
	Motorways & major roads	12-32	90-172	
	Urban roads	2-27		
	Gully Liquors	68-241		
	Misconnections	200-260		

focus of this study is primarily on prioritising the risks of stormwater pollutant sources from an acute impact perspective where MAC-EQS values are available and from a chronic impact when only AA-EQS values exist.

4 Methodology

4.1 Guidelines for identifying likelihood of occurrence and severity of consequences with respect to stormwater pollutants

The probability of specific stormwater pollutants from an identified source discharging to receiving waters via stormwater flow (likelihood of occurrence) and the consequences of this discharge on receiving water ecology (level of impact) can be assessed using a relative scale of 1 to 5, where the numeric values are pre-defined to represent either a comparatively escalating likelihood of occurrence or severity of impact (see Tables 1 and 2, respectively). A range of 1-5 was selected for benchmarking as the available data would not support a greater level of discrimination e.g. use of a scale of 1-100. Such a risk assessment approach is well recognised and accepted (e.g. EA, DETR and IEH, 2004; USDA, 2003). Whilst the use of quantitative data is preferred, this approach recognises that neither the impact nor the likelihood of an identified emission occurring can always be readily quantified, if at all. Hence, this methodology also supports the use of more qualitative data and the use of 'expert judgement' which, in the absence of field or literature data, is recognised as a pragmatic approach to managing the need to make decisions in the face of uncertainty.

4.1.1 Assessing the likelihood of pollutants occurring from an identified source discharging to receiving waters via stormwater flow

The likelihood of pollutants from an identified stormwater source discharging to receiving waters is defined through an evaluation of the concentration of pollutants transported during storm events with a low return period. Data to benchmark the level of likelihood might be available within the literature (e.g. published field data; see Table 1), through a theoretical consideration of the pollutant's physico-chemical characteristics (e.g. partition modelling) or, in the absence of data but availability of wider scientific understanding, the use of expert judgment. Table 2 provides guidance on the development of an approach to support the consistent assessment of the likelihood of a particular pollutant occurring in USW and hence discharging to receiving waters at elevated concentrations. Example descriptors given in Table 2 in relation to a particular level of likelihood are not meant to be exhaustive, but to generically illustrate how a range of 'likelihood of occurrence' data might be comparatively graded and associated with the allocation of a particular categorisation. The numeric values given to each likelihood grading are not necessarily intended to reflect a linear escalating scale of consequence or severity, such that a value of 4 is twice as severe as that allocated a value of 2. The numeric scaling may be linear but could also be applied in either a positive or negative exponential manner. Users of the methodology should be aware of the general relationship between the numeric values being allocated to specific gradings and be prepared to justify the scaling used.

Table 2. Guidance matrix to assess the degree of likelihood of a specific pollutant from an identified source occurring in stormwater

Likelihood of occurrence	Possible descriptors for relative grading	Numeric value associated with likelihood
Very high probability	Widely established in the literature that the pollutant regularly enters USW from multiple materials, activities or processes with EMCs an order of magnitude above reported background levels	5
High probability	Field data from several studies indicating pollutant enters USW from a single material, activity or process with EMCs consistently above reported background levels	4
Medium probability	Field data from a single study indicates presence of pollutant in stormwater flows with EMCs occasionally above reported background levels	3
Low probability	Field and modelled data indicate presence of pollutant in USW during some storm events	2
Very low probability	No field or modelling data available relating to presence of pollutant in USW	1

4.1.2 Assessing the consequences (severity) of stormwater pollutants from an identified source discharging to receiving waters

The consequence of stormwater pollutants from a specific source discharging into receiving waters is defined in relation to surface water quality impacts, through an evaluation of the potential for exceedence of the relevant standards within a specific surface water body. One approach to addressing this issue is to consider stormwater pollutant data (e.g. EMCs) in relation to the level of dilution associated with discharge into a receiving waterbody to gain an understanding of whether the relevant receiving water standard (e.g. EQS) will be exceeded. Where field data on stormwater loadings or knowledge of the concentration at which negative impacts occur is not available, it may be possible to use a modelling approach to theoretically calculate and compare a pollutant's predicted environmental concentration (PEC) with its predicted no effect concentration (PNEC) (Bound and Voulvoulis, 2004; Staples et al., 2000). Table 3 provides a matrix guidance template which stakeholders can use to support the consistent assessment of the consequences of stormwater pollutants discharging to receiving waters. As described in relation to Table 2, the example descriptions given in Table 3 are generic and only describe how a range of 'level of impact' data might be comparatively graded, and the numeric values assigned to the gradings could be linear (as indicated here) or non-linear in distribution.

Table 3. Guidance matrix to assess the level of consequence of an identified water quality threat/uncertainty occurring.

Level of consequence	Example descriptors for relative grading	Numeric value associated with consequence
Critical	Critical: complete system compromise e.g. regular failure to meet EQS or other regulatory standards during <1 year storm event; dilution factor required to meet EQS: >100	5
Damaging	Damaging: Consistent failure to meet regulatory requirements for < 1 year storm e.g. EQS failures; temporary loss of receiving water ecology; dilution factor required to meet EQS: 51-100	4
Significant	Significant: moderate impact with occasional exceedance of EQS; potential to cause public and/or political concern; tangible ecological and/or amenity damage; dilution factor required to meet EQS 11-50	3
Minor	Minor: minimum impact mainly associated with specific accidental discharges; some additional costs/efforts required; dilution factor required to meet EQS: 2-10	2
Insignificant	Insignificant: no impact felt on receiving water and no mitigating measures required; dilution factor required to meet EQS <2	1

4.2 Risk rating and prioritisation

The level of risk is assessed by combining information generated on likelihood of occurrence (Table 2) with data developed on the level of consequence (Table 3) through multiplying together the numeric values assigned to the gradings allocated, generating a 'risk score' for each pollutant associated with a particular source. The resulting level of risk associated with a pollutant from a particular source can then be interpreted using a risk rating scheme based on an initial 5 point scale, with subsequent combined values categorised as high, medium or low risk in relation to scores of 1-5, 6-14 and 15-25, respectively (see Table 4). Combining the likelihood of occurrence with the severity of the consequences can be used as a basis for visually illustrating the level of risk posed by stormwater pollutants associated with various sources and for a particular (sub)catchment.

Table 4. Matrix used to evaluate the level of risk

		Severity of consequence				
		Insignificant (1)	Minor (2)	Significant (3)	Damaging (4)	Critical (5)
Likelihood of occurrence	Very low (1)	1	2	3	4	5
	Low (2)	2	4	6	8	10
	Medium (3)	3	6	9	12	15
	High (4)	4	8	12	16	20
	Very high (5)	5	10	15	20	25

Key: Interpretation of overall risk: High = 15-25 (dark grey shading), Medium = 6-14 (medium grey shading), Low = 1-5 (pale grey shading)

5 Results and discussion

The developed method has been applied to data sourced from the literature on the levels of total suspended solids, lead, cadmium and biochemical oxygen demand in runoff discharging from rural and urban motorways. The level of risk associated with pollutants from two different sources is identified and its implications in terms of the development of pollution mitigation plans are discussed.

5.1 Risk assessment for total suspended solids (TSS)

Total suspended solids (TSS) are produced in the motorway environment through the erosion of road surfaces, vehicle emissions and vehicle part wear, seasonal maintenance practices and import from adjacent areas through atmospheric deposition processes (Revitt, 2004). Ranges of EMC values have been reported for TSS deriving from motorway surfaces due to influencing factors such as the different traffic densities experienced by different road systems, the nature of the surrounding catchment and the characteristics of storm events with low return periods. The range of TSS EMC values reported for European data in Table 1 become more extreme when results for US highways (1-5700 mg/L) are included (Revitt, 2004; Kayhanian et. al., 2007). However, the literature data more realistically supports upper TSS EMC values of 135 mg/L (DfT 2009) and 420 mg/L (Flint and Davis, 2007) for rural and urban motorways, respectively. Based on these values the likelihood of TSS being incorporated in motorway runoff and eventually being discharged into receiving waters at concentrations above the MIC levels reported in Table 1 is considered to have a high probability for rural motorways (score of 4 out of 5) and a very high probability for urban motorways (score of 5 out of 5) (see Table 2).

The factors which influence the impact of TSS on aquatic ecosystems include the TSS concentration, the duration of exposure, the geochemical composition of the TSS and the particle size distribution (Bilotta and Brazier, 2008). TSS water quality standards have been developed in Canada (CCME, 2002), United States (US EPA, 1976), Europe (EC, 2006) and Australia and New Zealand (ANZECC, 2000) but do not address all of these factors with only concentrations (as either TSS or turbidity) being commonly referred to. The EU Freshwater Fisheries Directive (EC, 2006) identifies a value of 25 mg/L for non-extreme conditions for the protection of salmonid and cyprinid fisheries. The reported EMCs for TSS in rural motorway runoff typically have mean values of less than 120 mg/L (Crabtree et al., 2006; Kayhanian et. al., 2007; Revitt, 2004) which implies a maximum 5 times dilution would be required to conform to the guideline value for receiving waters. In the case of urban motorways the corresponding value is a mean TSS concentration of 270 mg/L (Ellis and Mitchell, 2006; Kayhanian et al, 2007; Revitt, 2004) requiring a dilution of over 10 times. The dilution requirement for rural motorways is unlikely to result in anything other than minor ecological impacts to the receiving water system except in the case of very small recipients. Comparison to the European guideline standard for TSS suggests that the level of consequence can be considered to be low and has therefore been awarded a score of 2 out of 5. The increase in the consequences associated with the greater dilution required in the case of urban motorways merits a score of 3 out of 5. Therefore, the overall risk rating values for TSS in runoff are medium (8) for rural motorways and high (15) for urban motorways (see Table 5).

5.2 Risk assessment for biochemical oxygen demand (BOD)

Organic matter is in plentiful supply on motorway surfaces through both atmospheric inputs and direct vehicular deposition (Lopes et. al., 2000) although in terms of oxygen demanding potential the chemical oxygen demand in runoff is typically an order of magnitude greater than BOD (Ellis and Revitt, 1991). Measured BOD levels in motorway runoff are consistent with the limited supply of BOD in this environment and generally do not exceed EMCs of 10 mg/L for rural motorways (Crabtree et. al, 2006) and 25 mg/L for urban motorways (Revitt, 2004). These values are above the reported BOD background values (Table 1) but are only considered to represent a low probability of finding problematic levels of BOD in rural motorway runoff (score of 2 out of 5) increasing to a medium probability for urban motorway runoff where EMCs can occasionally significantly exceed the background concentrations (score of 3 out of 5) (see Table 2).

Water quality criteria represented by the River Ecosystem (RE) Classification have been developed for use in the UK (Stationary Office, 1994) to indicate the possible impact of increasing BOD levels on the ability of receiving waters to support different aquatic populations. Under this classification, a very good quality water which is suitable for all fish species (RE1) would have a 90 percentile BOD value not exceeding 2.5 mg/L and a poor quality water which is unable to support even a coarse fish population would have a 90 percentile BOD value not exceeding 15.0 mg/L. Given that BOD levels in rural motorway runoff are unlikely to dramatically exceed 10 mg/L, only a low dilution (of the order of 4 times) would be needed to achieve the RE1 classification within the receiving water. This is consistent with posing a minimum impact to receiving waters associated mainly with specific accidental discharges (score of 2 out of 5). The required dilution would increase to an order of 10 times for urban motorways implying a moderate impact with occasional exceedance of the EQS in the receiving water environment (score of 3 out of 5). The application of the risk rating approach to BOD in motorway runoff results in predictions of low (4) and medium (9) risk, respectively for rural and urban environments (see Table 5).

5.3 Risk assessment for cadmium (Cd)

There is considerable dispute in the literature about the affiliation of Cd to suspended solids with Kayhanaian et al (2007) suggesting that 60-65% of this metal in motorway runoff is in the particulate fraction whereas other researchers have identified Cd to be predominantly associated with the dissolved phase (cited in Opher and Friedler, 2010). There is also a lack of information discriminating between the toxic impact of dissolved and particulate associated Cd. Although Cd is not one of the most commonly found metals in the motorway environment, it is present in brake linings (2.7 mg/kg), tyre rubber (2.6 mg/kg) and de-icing salt (0.2 mg/kg) (Legret and Pagotto, 1999). These levels are lower than for certain other metals and when combined with the wear rates quoted for a standard vehicle translate into 78 ng Cd/vehicle km and 176 ng Cd/vehicle km for brakes and tyres, respectively. Therefore these sources represent a continuous but low input of Cd into the motorway environment which will then be available for incorporation into runoff. Davis et al (2001) have stipulated that 19% of the total Cd load to a motorway originates from atmospheric deposition and this may become a more important source on rural motorways. Wide ranges in the EMCs for total Cd in runoff derived from European motorways have been reported (Table 1) although for rural motorways the levels do not exceed 1.0 µg/L (Crabtree et al., 2006; Kayhanian et al., 2007). In contrast, urban motorway runoff EMCs can reach as high as 35 µg/L (Flint and Davis, 2007; Opher and Friedler, 2010). Therefore, although the identified possible inputs of Cd into the motorway environment indicate that there is a likelihood of it being present in all motorway runoff this is clearly more probable for urban motorways. Kayhanian et al (2007) have identified the presence of commercial areas in the land surrounding urban motorways as being a particularly influencing factor for total Cd. By referring to Table 2 there can be considered to be a medium probability of total Cd occurring at levels of concern in rural motorway runoff (a score of 3 out of 5) with this increasing to a high probability for urban motorways (a score of 4 out of 5).

Cd and its compounds are recognised by the EU WFD as priority hazardous substances and are assigned environmental quality standards which are appropriate to this status. The toxicity of Cd is related to the hardness of the receiving water with the maximum allowable concentration of dissolved Cd (MAC-EQS) varying from ≤ 0.45 µg/l (for a hardness of < 40 mg/l) to 1.5 µg/l (for a hardness of ≥ 200 mg/l). The reported total Cd EMCs in rural motorway runoff (0.4 – 0.9 µg/l) would equate to a range of 0.2 to 0.45 µg/l for dissolved Cd based on 50% being in this form. Hence, comparison with the strictest acute toxicity value would indicate that further dilution would not be necessary. However, in the case of urban motorway runoff, the highest monitored dissolved Cd concentration (8.4 µg/l; Kayhanian et al., 2007) would require a dilution of approximately 20-fold to achieve the same EQS. Although this may represent an extreme situation, it is a feasible scenario and therefore it can be deduced that there is the potential for a toxic impact in a receiving water due to the discharge of Cd in urban motorway runoff and hence a score of 3 out of 5 is allocated. The consequences for rural motorway runoff are considerably less representing a minimal impact to the receiving water environment (a score of 1 out of 5). Therefore, the overall risk ratings for Cd in runoff are low (3) for rural motorways and medium (12) for urban motorways (see Tables 3 and 5).

5.4 Development of risk assessment for lead (Pb)

There is clear agreement that Pb tends to be associated mainly with the particulate fraction with Kayhanian et al (2007) reporting that 83% of Pb is in this form. Direct Pb inputs into the motorway environment occur due its presence in brake linings (3,900 mg/kg), tyre rubber (6.3 mg/kg) and de-icing agents (3.3 mg/kg) (Legret and Pagotta, 1999). For a standard vehicle, the wear rates equate to possible inputs of 113 µg Pb/vehicle km from brakes and 428 ng Pb/vehicle km from tyres which are considerably higher than the corresponding inputs for Cd and therefore would be expected to lead to higher Pb concentrations in motorway runoff. Measured EMCs for European road systems confirm this (Table 1). However, there is a clear difference between the values for rural and urban motorways. Crabtree et al (2006) quote a mean EMC of 23.05 µg/l for total Pb in motorway runoff from 6 rural motorways in the UK and comparable data for the USA is represented by a mean value of 16.6 µg/l (Kayhanian et al 2007). On this basis the likelihood that Pb will occur at elevated concentrations and pose a problem for receiving waters due to it's presence on rural motorways is judged to be high and given a score of 4 out of 5 (Table 2). For urban motorways, Kayhanian et al (2007) report mean EMC values for total Pb of 23.5 µg/l (low annual average daily traffic flow) and 74.9 µg/l (high annual average daily traffic flow) with the latter being more consistent with mean EMCs of 96 µg/l reported by Revitt (2004) and an elevated value of 220 µg/l for a motorway in an ultra-urban area (Flint and Davis, 2007). The increased EMCs for Pb generated on urban motorways raises the need to have continued awareness of the potential problems that this may cause and a score of 5 out 5 is allocated indicating that there is a very high probability that elevated concentrations will exist in the receiving water environment.

In line with its identification as a priority substance with respect to water policy within the EU WFD, EQS values for surface waters have been proposed for dissolved Pb and its compounds. Only an annual average value of 7.2 µg/l exists but this also applies to protection against short term pollution peaks in continuous discharges as the value is significantly lower than the values derived on the basis of acute toxicity. Kayhanian et al (2007) have reported a mean dissolved Pb concentration of 3.2 µg/l in the runoff from non-urban highways which is compatible with the reported values for total Pb based on a 80/20 distribution between the particulate and dissolved phases. Therefore, to achieve the AA-EQS value for rural motorways, would not require any dilution of the identified EMCs. This represents an insignificant level of concern for the receiving water and merits a score of 1 out of 5 (Table 3). For heavily trafficked urban motorways the comparable dilutions, taking into account that 20% of the total Pb is in the dissolved form, would be between 2.1 and 6.1 signifying a minor potential to cause damage to the receiving water and an associated score of 2 out of 5 (Table 3). The dramatic reductions in recent years of Pb emissions to motorway environments, have resulted in reduced overall risk ratings of low for rural motorways (4) and medium for urban motorways (10) (Table 5).

5.5 Application of the risk rating approach

The results obtained by applying the risk rating approach to TSS, BOD, Cd and Pb in rural and urban motorway runoff are summarised in Table 5. As anticipated, runoff from rural motorways consistently poses less of a threat to receiving waters than urban motorway runoff with low risk situations identified for BOD, Cd and Pb whereas TSS present a medium risk in the rural motorway environment. Similar relative risk ratings exist for runoff from urban motorways with BOD, Cd and Pb all demonstrating medium risks to the receiving environment and only TSS showing a more serious high risk. Therefore, there is a clear need for mitigating measures to be introduced for TSS in stormwater deriving from urban motorways to reduce the perceived potential impacts to the receiving water. The situations categorised as medium risk should also be considered for remedial action based on the identified sensitivity of the receiving waters. The data in Table 5 provides guidance on the introduction of mitigating measures through consideration of the scores allocated to 'likelihood of occurrence' and 'level of consequence'. The high scores (5) awarded to 'likelihood of occurrence' for TSS and Pb on urban motorways indicate that remedial action, if deemed necessary, should target the input processes by which these pollutants are deposited on this type of road surface and the ease with which they can be washed off the surface. The highest score allocated to 'level of consequence' is a value of 3 for TSS, BOD and Cd in urban motorway runoff. In contrast to measures proposed to tackle likelihood of occurrence, the control objective here would be to treat the runoff prior to its discharge to the receiving waters hence reducing any detrimental impact it may have on the water quality and ecology.

Table 5. Risk rating scores for different pollutants with respect to rural and urban motorways

	Rural motorways			**Urban motorways**		
	Likelihood of occurrence	**Level of consequence**	**Overall risk score**	**Likelihood of occurrence**	**Level of consequence**	**Overall risk score**
TSS	4	2	8	5	3	15
BOD	2	2	4	3	3	9
Cd	3	1	3	4	3	12
Pb	4	1	4	5	2	10

Key: interpretation of risk score shadings - dark grey shading = high level of risk; medium grey shading = medium level of risk; pale grey shading = low level of risk.

The high risk predicted for TSS in urban motorway runoff suggests that mitigating measures should be introduced for stormwater deriving from this source in order to reduce the potential impacts to the receiving water. The risk analysis process indicates that source reductions of TSS are a priority to lower the 'likelihood of occurrence'. Eliminating vehicle and road surface wear would be difficult to achieve as would reducing incoming atmospheric deposition but it is feasible to control the input of solid material as a result of winter maintenance practices. In principle, motorway sweeping represents a way of reducing TSS levels which build-up during antecedent dry periods. However, there are reports that road sweeping practices remove less than 5% of the total solids (Opher and Friedler, 2010) and may result in the resuspension of fine sediments making them more available for subsequent washoff (Furumai et al, 2002). Therefore, additionally the use of structural stormwater BMPs should be considered to reduce the 'level of consequence' by treating the runoff prior to discharge to receiving waters. Scholes et al (2008) have reviewed the TSS performances of stormwater BMPs with greater than 80% removal efficiencies being reported for infiltration trenches, infiltration basins and sub-surface flow constructed wetlands, all of which could be used to treat urban motorway runoff. The situation with respect to TSS for rural motorways is categorised as medium risk with 'likelihood of occurrence' again representing the main risk contribution. Therefore, if remedial action is deemed necessary because of the sensitivity of the receiving waters, the preferred option would be to address the input processes by which TSS are deposited on this type of road surface followed by treatment of the discharged runoff.

The overall risk ratings for BOD in motorway runoff (Table 5) do not identify this pollutant as being of serious concern when discharged to receiving waters. The increase to medium risk determined for urban motorways is a function of the higher score given to the impact of the

BOD levels which can be derived from this environment. However, it is widely accepted that low level inputs of organic matter can be beneficial to the naturally occurring microorganism population and therefore there is unlikely to be a detrimental effect except in the case of a highly sensitive receiving water. However, where further elimination of biodegradable organic matter is needed, the installation of a suitable BMP would be appropriate. Scholes et al (2008) have developed a comparative assessment approach which identifies both surface and sub-surface flow constructed wetlands as well as infiltration basins as comprising efficient BMPs for the removal of BOD.

Cd is identified as posing a risk to receiving waters as a result of its presence in urban motorway runoff (risk score 12). Both the ‘likelihood of occurrence’ and the ‘level of consequence’ are identified as contributing to the medium risk associated with urban motorways and are areas where mitigating actions would be beneficial (Table 5). Therefore, there is a need to address both the Cd input to and washoff from urban motorway surfaces and also to treat the resulting discharge prior to it entering the receiving water. Ideally, the removal of Cd from various vehicle parts would reduce its direct deposition within the motorway environment. As for other metals, Cd exhibits a high affinity for the finer particles which are the most difficult to remove by sweeping practices but will be most readily washed off by rainfall events. Source control activities for Cd need to be supported by the use of BMPs to reduce the impact of discharged Cd to the receiving water environment. Infiltration basins and sub-surface flow constructed wetlands have been identified as potentially providing high Cd removal potentials. These BMPs maintain close contact between the incoming stormwater and an appropriate substrate together with attached microbial populations and/or plant roots enhancing the potential for processes such as adsorption, microbial degradation, plant uptake and filtration (Revitt et al, 2008).

As a consequence of the substantial reductions in recent years of Pb emissions to motorway environments, the risk ratings of low for rural motorways and medium for urban motorways are comparable with those for Cd (Table 5). However, an important difference can be observed in the weighting contributions with ‘likelihood of occurrence’ being the major influencing factor for Pb in both motorway environments. Therefore, remediation actions should focus on reducing the direct source contributions of Pb due to its presence in vehicle parts and to improving the mechanisms, such as street sweeping, by which the amounts of Pb deposited on motorway surfaces can be reduced. This is particularly important in urban environments where it is also evident that to achieve low risk status, treatment of the runoff prior to discharge would be beneficial. The BMPs which have been identified as being the most efficient for achieving Pb reductions are again infiltration basins and sub-surface flow constructed wetlands because of the variety of removal mechanisms which are available to remove this metal (Revitt et al, 2008).

6 Conclusions

The developed methodology enables quantitative and qualitative data from a range of sources to be combined to support a prioritisation of the risks to receiving water quality from stormwater runoff pollutants. Application to commonly determined organic and inorganic pollutants demonstrates the feasibility for assessing and discriminating between the relative magnitude of risks posed by pollutants from differing diffuse pollutant sources in an approach that is transparent and auditable. For example, the results presented here indicate that although the concentrations of TSS, BOD, Pb and Cd in motorway runoff pose a higher risk to receiving water quality when the motorways are located in urban as opposed to rural areas, only TSS exhibits a high level of risk. The use of the developed risk assessment and prioritisation framework offers a valuable contribution to the work of practitioners, regulators and policy makers in developing and implementing pollution mitigation plans. It provides a supportive tool in partnership discussions involved in developing and implementing the EU WFD programmes of measures from a variety of perspectives. These include the screening of identified diffuse pollution sources to determine those posing the greatest levels of risk to receiving water quality, informing whether identified risks are acceptable (and, if not, how they can be reduced, contained or managed), as well as contributing to the decision-making process with regard to the optimal allocation of infrastructure investments. Future work will focus on applying the developed risk assessment and prioritisation approach across a wider range of stormwater pollutants and sources at a catchment scale and quantifying methodological uncertainties.

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